

PREDICTING POSTFIRE PLANT SUCCESSION FOR FIRE MANAGEMENT PLANNING

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RESEARCH SUMMARY

Forest managers can model and predict the postfire succession of plant communities using existing and/or readily obtainable data. The methods presented require neither computation nor computer analysis. Examples are provided from the Northern Rocky Mountains, but the methods are applicable to any North American coniferous forest.

Choice of resolution levels, data bases, accuracy requirements, and method are related to management needs and available information. Three basic levels of succession modeling are presented which can meet a variety of resource management needs. A discussion of some basic considerations and constraints to using the proposed methodology is included.

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INTRODUCTION

Foresters must anticipate the probable occurrence and effects of natural processes on the forests they manage. They must also anticipate the probable response of forest vegetation to planned management activities. Fire is both a natural process and a management tool. Its occurrence, use, or exclusion can affect forest succession. Foresters need to understand how fire affects plant succession. The ability to predict postfire plant succession is especially important when developing, evaluating, and selecting fire management strategies for a forest and when using fire to manipulate forest vegetation.

Purpose

The purpose of this paper is to show how foresters can use existing knowledge and the results of recent research to improve their ability to predict postfire plant succession. The methodology presented is, essentially, a way of organizing available plant succession information into basic forest succession models. The problem of quantifying predictions of forest succession using the proposed techniques is discussed

PRELIMINARY CONSIDERATIONS

Intended Use

Predictions of fire-related plant succession are made or desired for different purposes. It is important that this purpose or intended use be clearly identified and defined before selecting a prediction method. A wilderness planner, for example, may wish to evaluate the probable effects of fire management prescription alternatives on the composition, age structure, and spatial occurrence of plant communities. Information needs in this case are rather general. A fire manager, who is developing a prescription for the use of fire to create big-game forage, requires more detailed information. In this case, the probable occurrence of specific plant species must be known.

Some important considerations when defining the intended use of fire-related plant succession predictions are:

The purpose of the predictions.—Will the predictions be used to evaluate the probable consequences of wilderness fire management prescriptions or to predict succession on a planned prescribed burn for wildlife habitat improvement? How will the predictions be used?

The planning level.—Are predictions for a forest-wide

area, such as a National Forest or Park, for a particular forest stand, or some other unit of area?

The vegetative units.—Are predictions desired for forest cover types, for habitat types, for particular species, or what?

The land management objectives for the area of interest.—Is timber production involved? Are important wildlife habitats present? What is the primary objective of management?

The importance of the predictions.—Is fire-related plant succession critical to site productivity, resource values, or other management goals? What are the consequences of wrong predictions?

A clear definition of the intended use of desired fire-related plant succession predictions is essential for defining three other important factors involved in method selection. These closely interrelated factors are resolution level and accuracy of the predictions and data requirements of the proposed modeling techniques.

Resolution Level

Resolution level refers to the amount of detail provided in the predictions of postfire plant succession. The appropriate level of resolution should be defined by the intended use of the predictions. Size of area is a major consideration. A low level of resolution may be appropriate for a large forest area, while predictions for a forest stand require a relatively high level of resolution. There is a strong interrelationship between resolution level and data availability. Data requirements change as the level of resolution changes. The level of resolution is often dictated by the availability of data or the capability to collect additional data. When such limitations exist, care must be taken not to misuse predictions. Do not, for example, apply broad forest-level predictions to individual forest stands.

Accuracy

Accuracy means freedom from error. It is a measure of the degree of conformity to a true value. Accuracy as used here refers to how well predictions of fire-related plant succession reflect what actually occurs.

The accuracy of predictions depends to a large extent on how well a succession model accounts for all the elements that govern plant succession on a site. Accuracy of predictions also depends on accuracy of data used to run the model. Accuracy is tied to resolution level.

Predictions that are accurate at a broad forest level may be quite inaccurate when applied to a forest stand. Desired accuracy, therefore, should be governed by the intended use of the predictions and the desired level of resolution. Accuracy will usually be less than desired because of poor or incomplete data and limited capability of available modeling techniques.

Data

Data ideally would be assembled to meet the needs of the model selected to provide predictions of the desired resolution and accuracy. Cost and time constraints often work against this ideal situation. Managers must often use existing or easily available data. This can, as previously noted, affect the resolution and accuracy of the desired predictions

An Example

The wilderness planning activity mentioned earlier can serve as an example of how the resolution-accuracy-data relationship might be dealt with in an actual management situation.

Assume, for the purpose of this example, a 1-million-acre wilderness area in western Montana. Detailed information about the vegetation is lacking and collection of such data is not planned. The planner needs to evaluate the probable impact of various fire management alternatives on wilderness plant communities. The overall need is to predict basic changes in plant communities under different fire regimens, including fire exclusion. A special need concerns the effect of fire or lack of fire on critical habitat for threatened wildlife species.

Since the overall need is to predict general successional trends following fire and in the absence of fire, a broad stratification system is appropriate. The Montana habitat type classification system (Pfister and others 1977) or habitat type fire groups (Davis and others 1980) meet this need. Mapping of individual habitat types is inappropriate for this level of resolution. General successional trends in the presence or absence of fire are provided for Montana habitat types (Davis and others 1980). This information can provide an adequate data base to obtain the desired predictions of basic changes in wilderness plant communities.

A higher level of resolution and more detailed information is necessary to obtain desired predictions of fire effects on critical wildlife habitat. The consequences of a wrong prediction are serious enough to warrant extra effort. Mapping and inventory of critical habitat areas and estimates of fuel loadings will provide a necessary

supplement to published information. Critical habitat features, such as thermal cover and browse species in the case of big game, nest trees for hole-nesting birds or old-growth forest for the pine marten, would require special attention during field inventory. Thus, within a relatively low resolution and general approach to succession modeling, predictions of a higher level of resolution and greater accuracy can be obtained for certain critical areas.

A more detailed discussion of interrelationships between resolution, accuracy, and data requirements is given by Kessell (1979a, 1979b). Further insight into these interrelationships is also provided in the discussions on modeling and predicting postfire plant succession which follow

MODELING AND PREDICTING POSTFIRE PLANT SUCCESSION

The traditional concept of succession (Clements 1916) assumes that a plant community that has been disturbed by fire gradually resumes the structure and composition that existed before the fire occurred. This recovery is accomplished by an orderly and predictable series of species replacements. The initial postfire community is assumed to be composed of "colonizer" or "pioneer" species which are intolerant to shade and therefore unable to replace themselves indefinitely. Other, more shade-tolerant species gradually take the place of the pioneer species. Progressive species replacement continues until tolerant species that can replace themselves indefinitely occupy the site. This is the mature or "climax" community. Results of recent ecological studies suggest that the traditional approach to plant succession is inappropriate in many fire-prone communities.

Results of studies (Connell and Slatyer 1977) indicate other replacement patterns generally have been found. Evidence suggests several possible successional sequences or pathways that a plant community might follow after a fire. The pathway followed by an individual community is a function of the species' characteristics, the fire periodicity, and the fire's intensity (Noble and Slatyer 1977; Cattelino and others 1979; Kessell and Potter 1980). The composition of the preburn community is an important determinant of postfire succession (Lyon and Stickney 1976; Connell and Slatyer 1977).

On the following pages, techniques are presented for describing and predicting fire-related plant succession in accordance with modern ecological thought. Emphasis is on the techniques and how they can be used to aid forest management. We have purposefully oversimplified some ecological processes in order to emphasize techniques.

Such situations are noted in parentheses

The information needed to use the proposed techniques is as follows.

A plant community stratification system (community types, timber types, habitat types, gradient model, or the like);

Basic information on structural changes which occur after a fire (e.g., an initial grass-forb stage being gradually replaced by shrubs and seedlings, to be replaced by larger trees, etc.);

Basic information on the major tree species changes through succession (e.g., lodgepole pine gives way to Douglas-fir and subalpine fir, etc.); and

Rudimentary knowledge of the relationship between fire intensity and gross fire effects (e.g., relatively intense fires kill the trees, but a mild fire kills only seedlings and understory plants).

The more refined techniques require additional information on the degree of fire resistance, other adaptive characteristics, and life history of tree species. Seeding requirements, relative tolerance, age when reaching maturity, and average lifespan are examples of the kind of additional information needed.

Sources of such information are identified in the discussions that follow

Broad Approaches

Broad, low resolution approaches to succession modeling usually involve stratification of a forest into vegetative units that exhibit similar general successional characteristics. The models take the form of narrative and simple graphic representations of the general successional trends that can be expected to occur in the different vegetative units. The Montana habitat type series (Pfister and others 1977), the habitat fire groups (Davis and others 1980), and the ecological land units (Aldrich and Mutch 1973) are examples for Northern Rocky Mountain forests. The nature and utility of broad, low resolution level fire-related forest succession models are illustrated below using the fire groups of Montana habitat types.

The habitat type fire groups (Davis and others 1980) were developed to aid land management planning on the

Lolo National Forest. The concept was later expanded to include all forest habitat types in Montana. The basis for a fire group is similar response of tree species to fire and a similar postfire succession. The fire groups and the habitat types that comprise them are given in the appendix. Successional diagrams for each fire group show basic trends in structural changes and tree species succession. The diagrams also show general responses to fires of different intensities and different stages of recovery from the last fire. Figure 1 shows the succession diagram for Fire Group 6, a group of moist Douglas-fir habitat types. The immediate postfire community is an herb and shrub cover which is replaced by seedlings and saplings of ponderosa pine (PIPO), lodgepole pine (PICO), western larch (LAOC), and Douglas-fir (PSME). The next stage is pole-sized trees of the same species. This is followed by mature trees of the same species. If fire is excluded for a sufficiently long time (about 400 years), a climax community of pure Douglas-fir is reached. Thus the solid arrow shows in general terms the community's response to a single fire.

The diagram also shows the responses to additional fires. A fire that occurs at the herb/shrub stage maintains that stage. A fire that occurs at the sapling stage can either return the stand to herb/shrub cover or serve as a thinning fire (killing some, but not all of the trees) in an older stand of larger saplings. The effect of a fire that occurs in a stand of pole-sized trees will depend on the fire's intensity. A light fire in such stands will maintain a community of ponderosa pine, lodgepole pine, and western larch by removing tolerant understory species, while a severe fire will kill all the trees and the stand will revert to herb/shrub cover. Fire's effect in the older stands is similar.

The simple diagram shown in figure 1 presents useful information on fire relationships in the plant communities for which it was developed. First, it describes structural changes which occur following fire. Second, it shows changes in overstory species composition following a fire. Third, it relates fire effects to the stage of recovery from the last fire. And fourth, it relates fire effects to broad classes of fire intensity.

Each succession diagram constructed by Davis and others (1980) is accompanied by a brief discussion of the role of fire in the fire group (exhibit 1) and a step-by-step explanation of the succession processes illustrated in the diagram (exhibit 2). Both of these narrations are based on a review of existing literature, most of which is readily available.

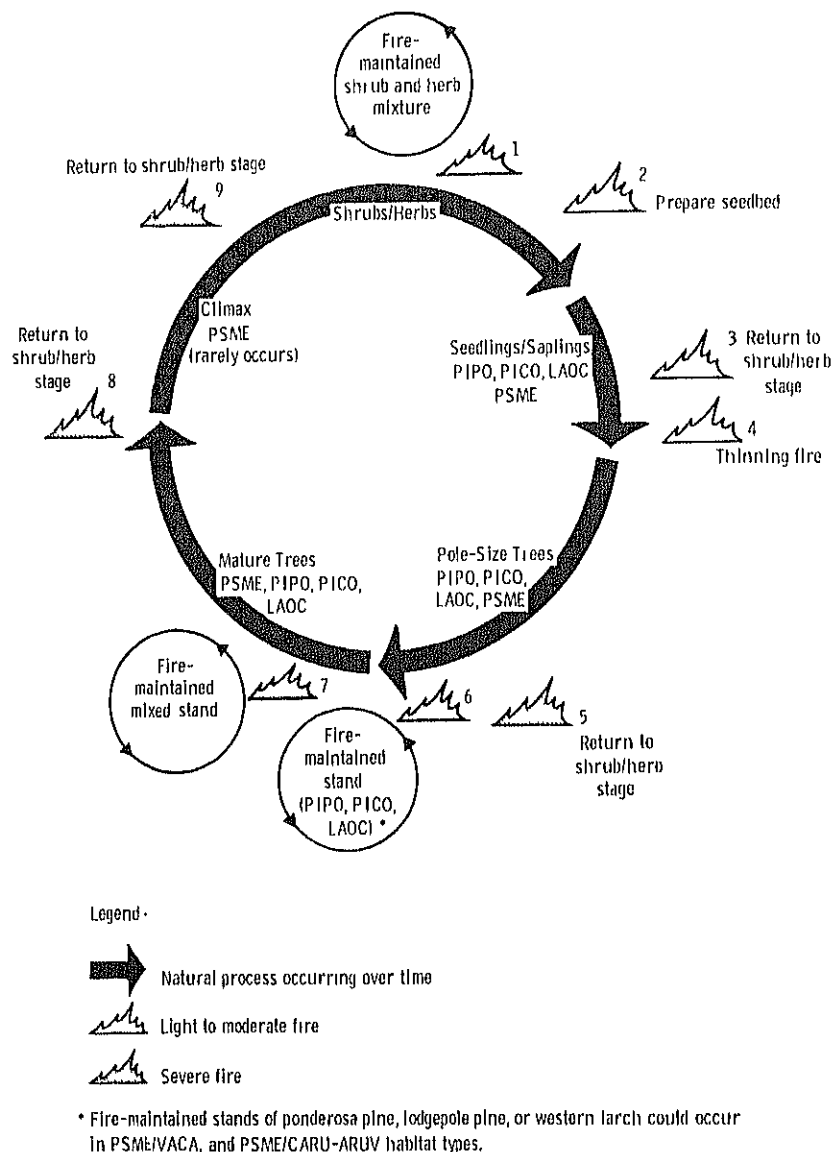


Figure 1.—Forest succession in the Davis and others (1980) Fire Group 6 (moist Douglas-fir habitat types).

Exhibit 1.—The “Role of Fire” in Fire Group 6; moist Douglas-fir habitat types (from Davis and others 1980).

Fire appears to be very important in Group Six as a seedbed-preparing and stand-thinning agent. Fire favors the pioneer species ponderosa pine, lodgepole pine, and western larch in Group Six. In stands that have escaped regular ground fires for several decades, flames can climb through the Douglas-fir understory into the overstory, developing a crown fire or torching the canopy.

Fire has a demonstrable effect on wildlife habitat in this group through its effects on food plants. An important species in some habitat types is *Vaccinium globulare* (blue huckleberry). Light burning in the early spring stimulates huckleberry to produce more shoots. Late summer or fall burning, however, reduces the number of huckleberry plants since it tends to be more intense. Because of heavy use by grouse, bear, deer, and elk, spring burning is preferred in areas designated for wildlife habitat.

The historical frequency of fire in a group of stands similar to Group Six was given by Arno (1976). The mean interval of fire occurring somewhere in sizeable stands (100 to 200 acres; 40 to 81 hectares) was about 28 years with a range of 5 to 67 years during the two centuries from 1700 to 1900.

Exhibit 2.—Narrative explaining the succession diagram for Fire Group 6 (fig. 1); moist Douglas-fir habitat types (from Davis and others 1980).

Secondary succession in Group Six begins with a mixture of shrubs and herbs. Conifer seedlings may be a minor component of this stage. Frequent fires will maintain a predominant shrub and herb community by killing conifer regeneration (. . . No. 1). Tree seedlings may become established in the seedbed created by fire or germinate on the site during a prolonged period without disturbance. Conifers appearing in this stage will depend on the seed source, but, generally there will be at least two species represented. Because Douglas-fir is more aggressive in these habitat types than in Group Four (warm, dry Douglas-fir habitat types), it is often found in young stands.

A fire during the seedling/sapling stage will have the same effect it would have had in previous groups. The vegetation will be returned to a shrub/herb community (. . . No. 3) or the regeneration will be thinned (. . . No. 4). More continuous ground fuels occurring in these habitats increase the probability of more complete burns.

When the trees are pole-sized, a severe fire could destroy the stand (. . . No. 5). Site productivity is moderate-to-high in Group Six habitats, and dense stands do develop. Fuel ladders and suppression mortality increase the potential destructiveness of fire during this successional stage.

Ground and surface fires of lower intensity maintain open seral stands. In some habitat types (PSME/VACA and PSME/CARU-ARUV), ponderosa, lodgepole, and/or larch may be dominant (. . . No. 6). In the other habitats where Douglas-fir is more aggressive, the fir will usually dominate a mixture of the seral trees (. . . No. 7). The species composition largely depends on the seed source and influence of past fires.

Long periods without fire can result in the establishment of a dense Douglas-fir understory which can act as a fuel ladder to the overstory. A severe, stand-destroying fire in a closed mature stand will recycle the site to a shrub/herb stage (. . . No. 8).

A climax forest composed only of Douglas-fir is not likely to occur in the Group Six habitat types where ponderosa, lodgepole, and larch are prominent components; primarily because the interval between fires is shorter than the life span of seral trees. However, some Group Six stands, notably on PSME/PHMA-PHMA and PSME/CARU-CARU h.t.'s, often achieve near-climax status because Douglas-fir is the only important tree even in early succession. Intervening fires are generally light to moderate and do not disrupt succession. A stand-destroying fire in a climax stand would return the vegetation to a shrub/herb dominated community (. . . No. 9).

Huckleberry can be stimulated by light burning which leaves most of the duff, or alternatively, it can be temporarily reduced by a moderate fire that burns down to mineral soil.

The graphic display of information shown in figure 1 illustrates general fire-related successional trends. The format does not easily allow the addition of more detailed information.

The diagram in figure 2 illustrates a more flexible format for displaying information identical to that displayed in figure 1. Three simple rules govern the use of this new format:

1. Successional changes which occur in the absence of further fire are shown as solid lines (arrows).

2. Successional changes which result from additional fires are shown by broken lines (arrows).

3. If different responses are possible depending on the fire's intensity, more than one broken line is drawn. Each is labeled with the fire intensity which causes that transition (low, moderate, high, or any).

In the following discussion, figure 2 is used to show how a fire-related forest succession model can be constructed for a forest area. Key requirements for predicting succession and techniques for increasing the resolution of a basic model are discussed.

—————▶ Succession in absence of fire
 - - - - -▶ Response to fire
 Lo (light or moderate fire)
 Hi (high intensity fire)
 Any (any fire)

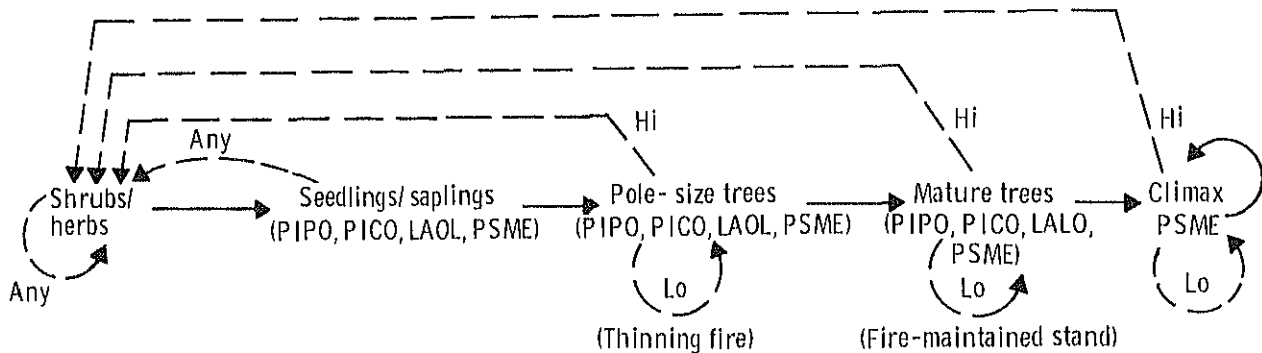


Figure 2.—A diagram adapted from figure 1. Solid lines show successional transitions in the absence of further fires. Broken lines show the response to additional fires. Where multiple transitions are possible, the fire intensity determines the path followed.



Figure 3.—The first step in constructing a succession model for a new set of communities is determining the transitions without fire from one structural stage to another.

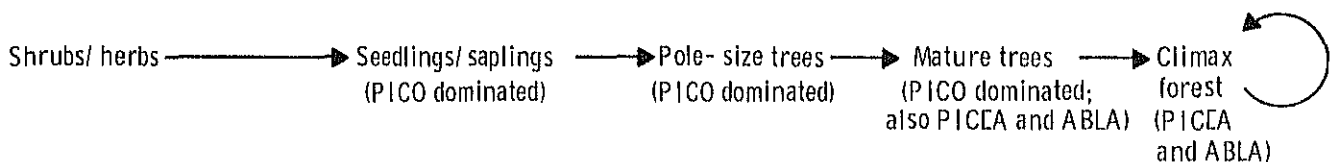


Figure 4.—The next step in constructing the succession model is adding the major tree species for each successional stage. The example given here is a succession model for cool, moist habitat types usually dominated by lodgepole pine (PICO).

The diagram in figure 2 shows five basic "states" in which a forest community can exist: "herb/shrub"; "seedling/sapling"; "pole-size trees"; "mature trees"; and "climax forest." These states are essentially structural divisions of the process of continuing changes through succession. These states may be distinguished without reference to species composition. Such structural changes are probably the most obvious effects of postfire succession. They can be readily characterized for a specific forest area. The 5-state sequence shown in

The first step in building a model for a local forest is to draw the partial succession model shown in figure 3. The arrow in the last state, which closes on itself, indicates that the stand remains in this state indefinitely in the absence of further disturbance.

The next step in model construction is to further describe the structural stages by including information on the predominant tree species. Figure 4 illustrates this

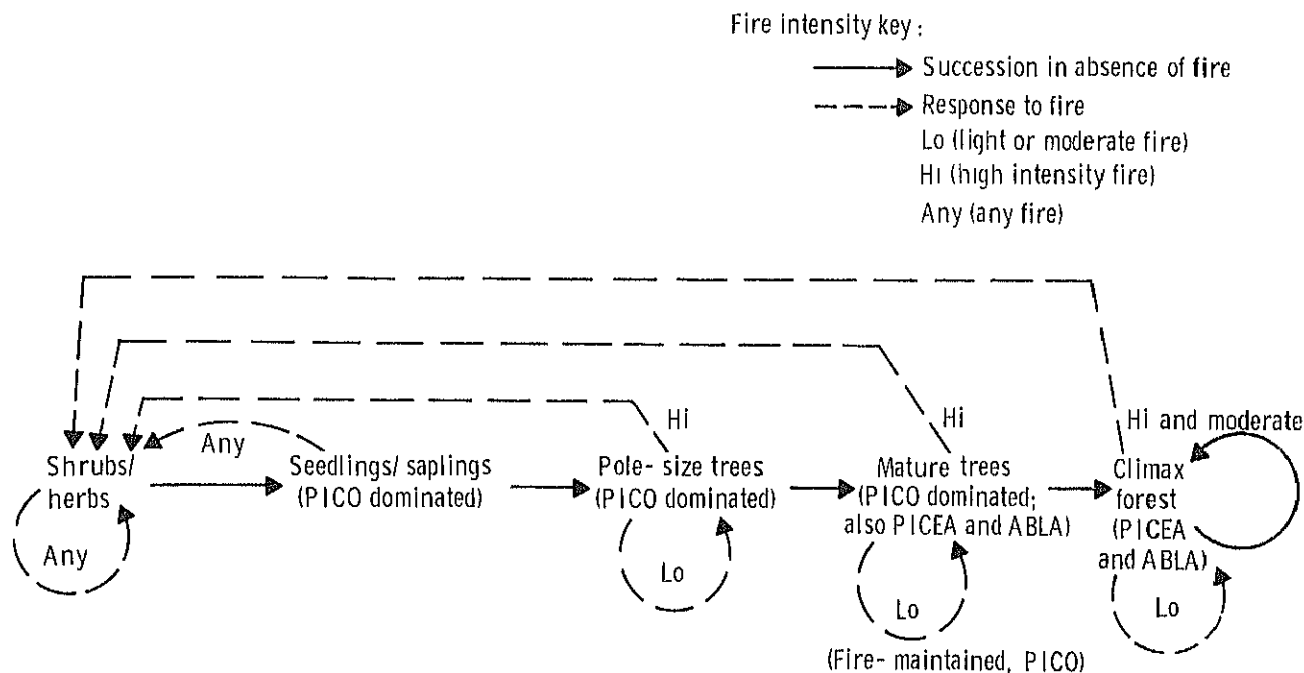


Figure 5.—The final stage of constructing a model at this resolution level is including the transitions after another fire (broken lines) and the types of fire which cause each transition.

step for a forest characterized by cool, moist habitat types which are usually dominated by lodgepole pine (PICO) and rarely achieve a climax of spruce (PICEA) and subalpine fir (ABLA).¹ Arno² details the same information in diagrams for ABLA/XETE and some other Montana habitat types.

The next step is to add the additional successional changes or "transitions" caused by further fires. In western Montana, the lodgepole pine forest depicted in figure 4 and the Douglas-fir habitat types shown in figure 2 would respond to fire similarly. Fires in young stands cause a transition back to the herb/shrub stage, mild fires in older stands either maintain the stand or set it back slightly, and severe fires in older stands also cause a transition back to the herb/shrub stage. Figure 5 shows this final stage of model construction at a broad, low resolution level. This diagram is analagous to the one shown in figure 2 for Douglas-fir communities, except that it represents the lodgepole pine communities and is drawn from readily available information. (It should be noted that a fire of moderate intensity in the ponderosa pine, Douglas-fir, and western larch stands of figure 2 could maintain the stands, whereas a medium intensity fire in the lodgepole pine stands of figure 5 would

probably cause mortality of overstory lodgepole pines, perhaps through bole heating.)

It is possible to construct similar diagrams or models for most forest areas using fairly simple, readily available, and readily observable information. These models are nothing more than a convenient and useful way to assemble and view existing knowledge. They offer a simple means of describing basic fire succession relationships at a rather broad level. There are, however, many pertinent questions which these models cannot answer. Examples of such questions are:

At what ages do the basic transitions occur? How long does it take to reach the "mature trees" stage?

What critical fire intensities distinguish a "severe" burn from a "light" or "moderate" one?

How do the densities or importance of tree species change from state to state?

How do undergrowth species fit into the picture?

Are other pathways possible? Can extremes of fire periodicity or fire intensities cause other transitions not shown here?

To answer such questions, more refined methods, which build upon the basic system already presented, have been developed. These methods are discussed below.

¹This is Fire Group 7 in the Davis and others (1980) system; individual habitat types included are listed in the appendix.

²Arno, Stephen F. 1979. Classification of seral communities for major habitat types in western Montana and central Idaho. Second annual progress report, Study INT-1205-587. USDA For. Serv., Internl. For. and Range Exp. Stn., For. Sci. Lab., Missoula, Mont.

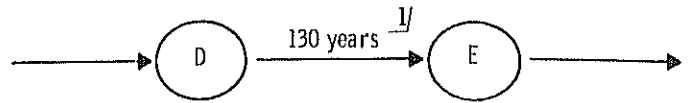
Potential Refinements

Refinement of a basic model to include more detail requires more information. Adding to the model information about the ages of the transitions from one state to another requires information on the growth and life histories of the tree species. Unless such information is available, field data must be collected. The simple approach is to locate stands in the field which correspond to the various states, or which represent transitions from one state to another (e.g., a "pole" stand which has nearly reached the "mature trees" stage) and determine their ages from fire history records, forest inventory data, increment cores, etc. The transitions usually represent a range of ages, rather than making this particular transition at "age 62 years," a more reasonable datum might be, "it makes the transition at from 55 to 70 years of age."

Similar field observations or forest inventory data can be used to refine the species composition descriptions of each state, but only within certain limits. Here the problem of resolution level comes into play. Habitat type groups have been used in all the models presented so far. These rather broad collections of different individual habitat types are only appropriate at broad resolution levels. Attempts to refine species composition information or other aspects of the model require a refined vegetative stratification system or detailed vegetative analysis of individual habitat types. A smaller group of fewer and more similar types, or even a single habitat type or phase may be appropriate.

A more refined vegetative system allows calibration of a model to include a more complete description of overstory species changes through succession. Information about undergrowth species can also be included, if such information is available or can be otherwise obtained. If such data are available in the form of published studies or forest inventory data, they can often be adapted to succession modeling. If such data are not available, they can be collected in the field (Pfister and Arno 1980). Data collection techniques should be statistically sound with special emphasis on avoiding bias. Care should also be taken to collect data that truly represent the vegetative communities to be modeled. Do not, for example, collect data from natural stands and indiscriminately apply it to managed stands.

One useful refinement to the succession models is based on the life history and adaptive characteristics of the tree species. It requires some basic information on each species of concern; namely, method of reproduction, relative tolerance, age at maturity, and longevity. This information must be determined locally, since, even for a single species, it can vary from one



1/ stand age

Figure 6.—A portion of a succession model showing loss of an intolerant species at age 130 years (the number shown on the solid line transitions is stand age in years). State D and previous states included the species, but State E and subsequent states do not.

habitat type to the next. Refinement of succession models to consider species loss following fire will demonstrate how such information can be used. The refined succession diagrams are similar to those used to demonstrate broad, low resolution models. Solid lines indicate succession without fire and broken lines indicate succession after an additional fire. States are represented by circled letters. In any given community, the states represent a combination of structural development and species assemblage.

A tree species' capability to reestablish itself in a postfire stand was assumed in the models presented previously. There are, however, circumstances under which a species will not reestablish, or will reestablish poorly following fire.

Once a tolerant species becomes established in a community, it will remain there at least until a further disturbance. An intolerant species usually will not, however, replace itself in the absence of further disturbances. Aspen, for example, is intolerant, becomes established immediately after a fire, but lives for only about 130 years. A transition from one state to another in the model is required at age 130 years as shown in figure 6. State D includes aspen, but State E and subsequent states do not. Thus the life span of an intolerant species is a critical age which determines a transition required by the succession model.

To illustrate further the role of critical ages, consider a species which is unable to disperse into a stand or to reproduce vegetatively, and therefore must regenerate from stored seeds. If this species is also intolerant, it will eventually be lost, for all practical purposes, from the stand. It will also be unable to reestablish after a fire if its seeds are no longer viable. Thus a sufficiently long time between fires will result in its virtual loss from the community. This situation is shown in figure 7 using serotinous lodgepole pine as an example. This is really a hypothetical example since natural populations of lodge-

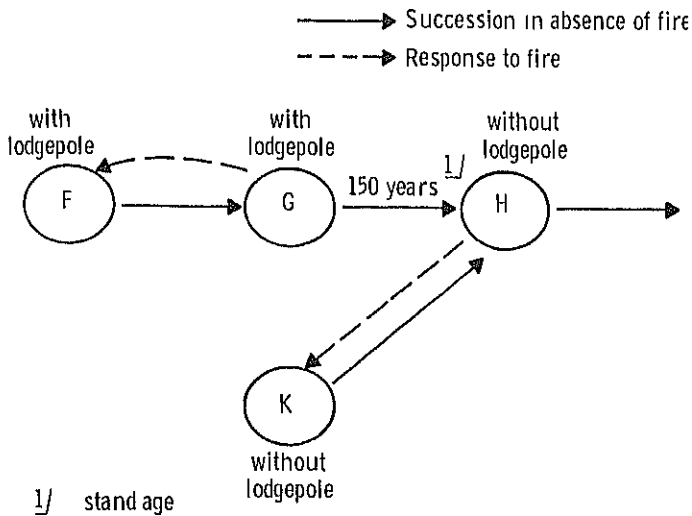


Figure 7.—A portion of a succession model showing loss of a stored seed-reproducing intolerant species (PICO). The species is virtually lost from the community at age 150 years in the transition from State G to State H. A fire in State H causes a transition to State K, in which the species is unable to reestablish.

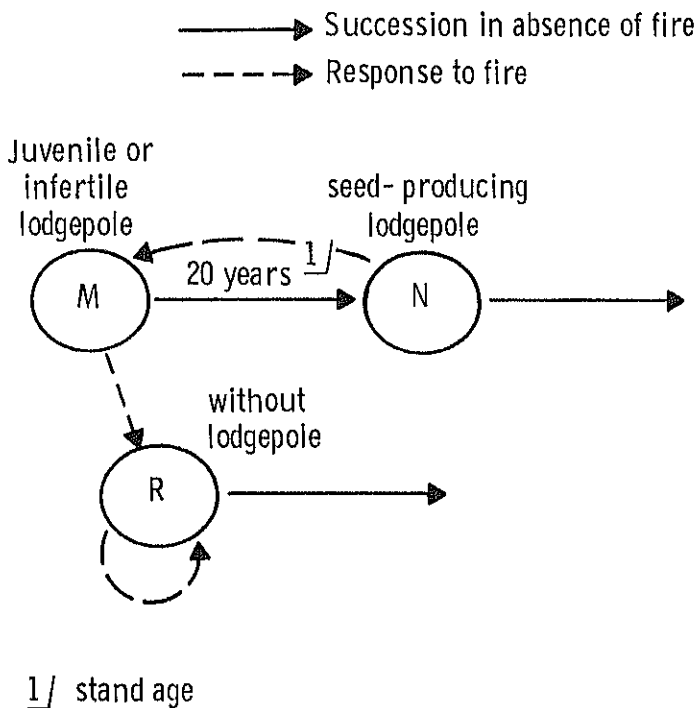


Figure 8.—A portion of a succession model showing loss of a stored seed-reproducing species (PICO) caused by burning a young stand. The species requires 20 years to produce seeds, and so a severe disturbance to State M causes a transition to State R and results in the species' virtual loss from the stand.

pole pine usually include both open and serotinous cone seed dispersal. A survey of cone serotiny in the Rocky Mountains (Lotan 1975) found 32 percent of stands to have fewer than 10 percent serotinous trees (defined as having at least 90 percent closed cones). Only one-quarter had more than 50 percent serotinous trees and none had more than 90 percent (Perry and Lotan 1979). States F and G (fig. 7) include lodgepole pine; its loss is indicated by the transition to State H at an age of about 150 years (its lifespan in this community). But a disturbance in State H causes a transition to State K, which includes no lodgepole pine. It is not possible to return to States F or G once State H has been reached because of the loss of the pine's seed source. This same process also occurs with vegetatively reproducing intolerant species, such as aspen in the example given above, but

does not occur with intolerants which regenerate from dispersed seeds.

Serotinous lodgepole pine, as a stored seed species, additionally serves to illustrate another critical age situation. If a stand in which such lodgepole pine is present burns, the lodgepole pine vigorously regenerates from its stored seeds. This process uses the existing lodgepole seed source. New lodgepole pine seeds will not be available for about 20 years—until the regenerating pine reach maturity and produce seeds. If this stand burns again during this 20-year period, the presence of lodgepole pine in the stand could be significantly reduced because of lack of seed. The species could even be lost for a long time. Figure 8 shows this process; burning State M, which includes young

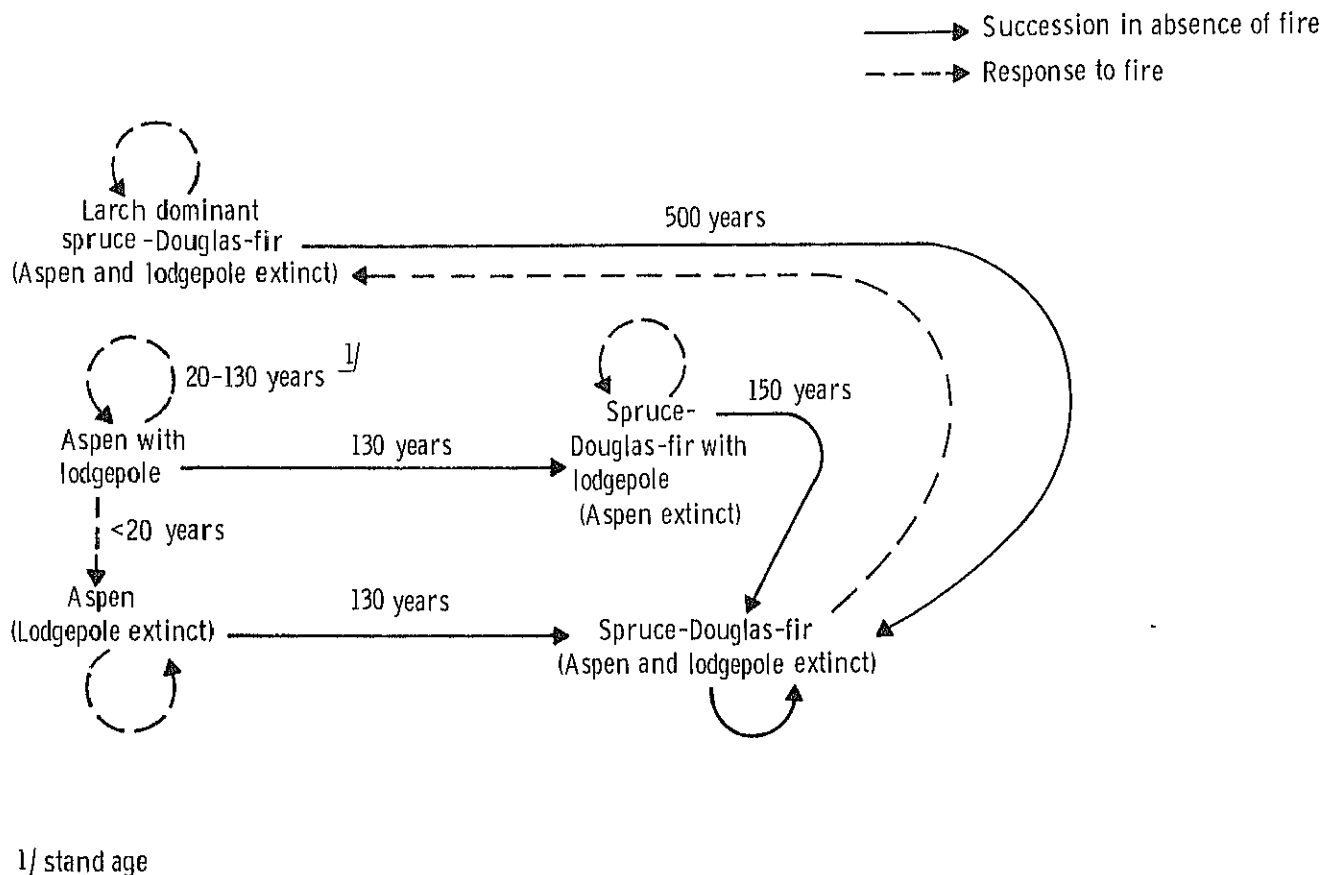


Figure 9.—Succession model of an aspen community which illustrates how species adaptations and fire periodicities can cause the loss of certain species under very short or long periods between fires. (For further explanation, see the text.)

lodgepole pine, causes a transition to State R, and the pine is essentially lost from the new postfire community.

Several situations which cause species loss from a plant community can be combined into a single model. An example is the model of an aspen community from the west slopes of Glacier National Park, Mont., developed by Cattellino and others (1979). These aspen communities exhibit a mean fire-free interval of about 50 years and are composed primarily of aspen, serotinous and nonserotinous lodgepole pine, ponderosa pine, Douglas-fir, spruce, and western larch. A fire in these stands leads to a succession which normally includes all of these species. Yet, field observations (Kessell 1979a) revealed the following exceptions to this general rule:

1. Under a long period between fires, some stands lose aspen before the second fire, with lodgepole pine, western larch, ponderosa pine, and/or Douglas-fir increasing their importance;

2. By the time a second fire has ended a long period between fires, some stands have lost both aspen and lodgepole pine, but a dramatic increase of western larch occurs; and

3. It is suspected that, under short periods between fires, some stands lose the lodgepole pine and have a dramatic increase in aspen.

To model this community, we need information on the adaptive traits and life history of each species. Aspen is an intolerant species and reproduces in these communities primarily by resprouting. It lives for about 130 years. The serotinous lodgepole pine is also intolerant, requires about 20 years to produce seeds, and lives for about 150 years. All of the other species reproduce primarily from dispersed seeds. Larch is intolerant, while both spruce and Douglas-fir are tolerant. (These examples are purposefully oversimplified. Although generally unable to regenerate from seed in the aspen communities under discussion, aspen does seed in regularly to clearcuts and road cuts in the ABLA/XETE, ABLA/MEFE, and some other habitat types observed by Stephen F. Arno [personal communication]. Also, western larch probably stores viable seed in its crown during fire.)

The model of this community is shown in figure 9. The "normal" community is the "aspen with lodgepole pine" stand. If it burns with its normal fire periodicity of about 50

years, it remains an aspen and lodgepole pine community with lesser amounts of the other species. If, however, the community goes 130 years without a fire, the aspen is essentially lost from the stand. Burning the stand now causes a different successional transition to a spruce, Douglas-fir, and lodgepole pine community. If this same community goes 150 years without a fire, the lodgepole pine is also lost, and a spruce and Douglas-fir stand remains. Burning this stand causes a still different transition to a larch-dominated seral community. This community, if left undisturbed for about 500 years (the approximate minimum lifespan of intolerant larch), will eventually revert to a spruce and Douglas-fir community. If burned again within the 500-year period, it remains a larch-dominated stand with lesser amounts of spruce and Douglas-fir. The final possibility is to burn the original aspen and lodgepole pine community within 20 years of the last fire. The lodgepole pine has not yet produced seeds; so either it will not regenerate or it will regenerate poorly from dispersed seeds. The result is a community that is almost pure aspen.

Obviously, this kind of model requires considerably more field data and knowledge of species' characteristics than do some of the earlier examples given. Yet, it can show certain fire regimens that could drastically alter the community because of the loss of one or even two of the major species. Once again, intended use of the information yielded by the model must be balanced against efforts required to obtain the data needed to develop the model.

Despite the apparent sophistication of the above model of the aspen community, further refinements are possible—for instance, the quantification of species abundances through time, and the relationship between fire intensity and the fire's effects on the plant community. The addition of undergrowth species to the model would be a significant refinement.

Quantifying the Predictions

Some management applications of succession models require a quantified prediction of species changes. Knowing that huckleberry will be present after a fire, for example, might not be good enough. Information on the amount of ground covered by huckleberry, 5 percent or 50 percent, may be necessary. Information on the plant's fruit production might be most important. Collection of sufficient field data to calibrate the model to local conditions is required to obtain such resolution.

For example, consider the general succession model shown in figure 10. It could apply to many different communities, but here it will represent a hypothetical Douglas-fir habitat type which includes successional ponderosa pine and lodgepole pine. In this example,

Douglas-fir is tolerant (actually intermediate in tolerance) and the climax species. Lodgepole pine is intolerant and reproduces only from serotinous cones; therefore, a very short or very long period between fires will cause a greatly diminished presence in the community. (In reality, nonserotinous lodgepole pine would also have to be included.) The third species, ponderosa pine, is intolerant, regenerates from dispersed seeds, and lives for about 400 years.

The immediate postfire State A includes herbs, shrubs, and seedlings of all three tree species. This state gives way, after about 20 years, to State B, which again includes all three species. After about 220 years, which is the average lifespan of lodgepole pine in this particular community, a transition is made to State G, which includes ponderosa pine and Douglas-fir. Finally, after about 400 years (the lifespan of ponderosa pine), it reaches State H, which is pure Douglas-fir. The community stays at this state indefinitely until another severe fire occurs. (In reality, some low intensity ground fires which characteristically occur in these forest types would have to be included in this model.)

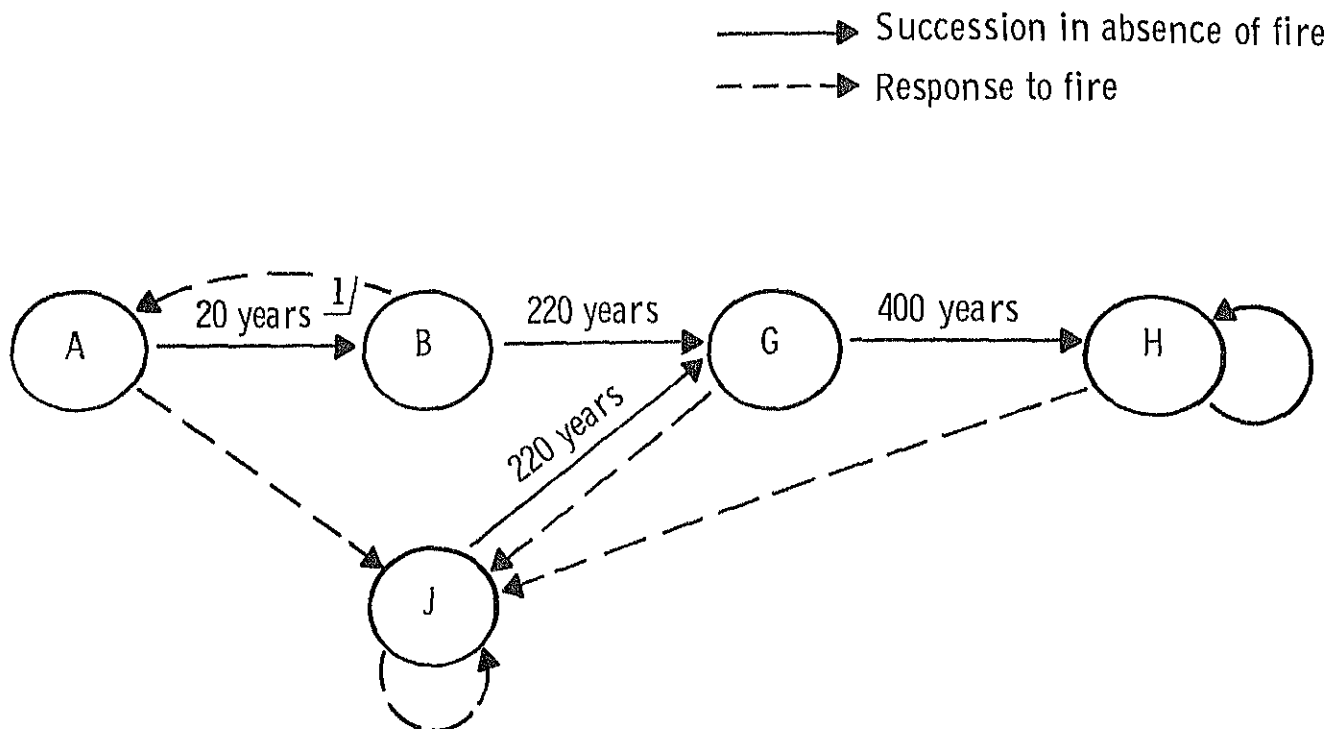
State J represents a community which has lost serotinous lodgepole pine, either by having a second fire within 20 years, or by going more than 220 years without a fire. The broken lines indicate the transitions after another fire.

This model could be quantified by sampling stands which represent each state and so draw up a list of species composition and importance values for each state. But, a problem immediately surfaces. State B represents stands which range in age from 20 to 200 years. This situation presents no problem when only presence or absence of species is dealt with; all three tree species are present within this age span. Yet, when we try to quantify species importance, we find some major changes occurring over this period; both ponderosa pine and lodgepole pine slowly decline while Douglas-fir increases its number. In order, therefore, to use field data to quantify this model, more states must be recognized.

A model which does this is shown in figure 11. The previous States B and J (fig. 10) have been replaced with several states. Transitions now occur at (somewhat arbitrary) 50-year intervals. This provides a framework whereby, with sufficient data, a quantitative list of species composition for each state can be compiled and changes predicted at 50-year intervals.

Once again, the degree of refinement depends on information needs and ability to obtain the required data.

A more difficult quantification problem is that of relating



1/ stand age

Figure 10.—A model of a simple forest community which includes Douglas-fir, ponderosa pine, and lodgepole pine. Transitions show where species may be lost from or added to the community. (See text for further explanation.)

fire effects and choice of successional pathway to measured or predicted fireline intensity. A severe fire has a very different effect than a mild one, but what constitutes a severe fire? An intensity of 200, 500, or 2,000 Btu/ft/s (692, 1 730, or 6 918 kW/m)? At this stage of current understanding, experienced judgment can probably serve just as well for determining what circumstances produce severe fires that cause major successional changes. General guidelines for estimating these effects from fuel, weather, and community data are currently lacking. Research efforts, however, are underway to estimate critical fire intensities for specific community types.

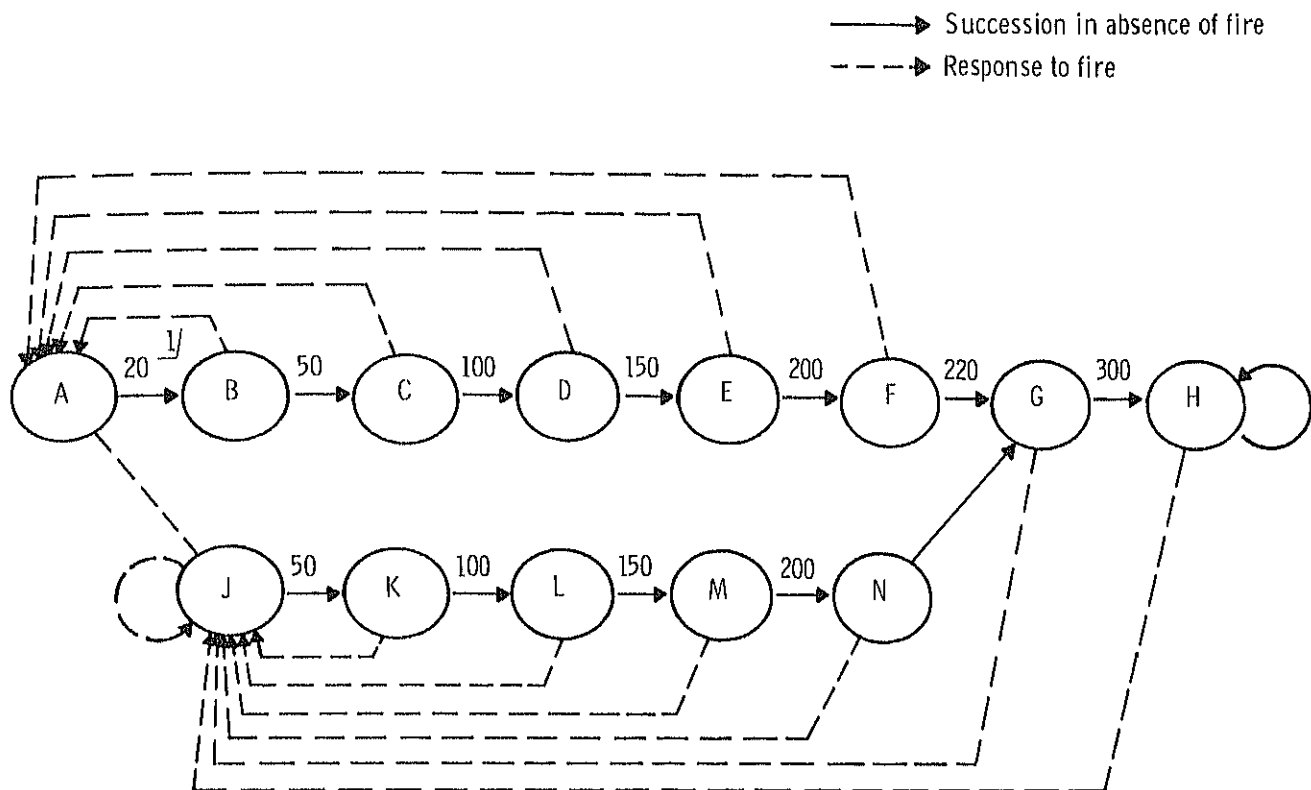
For example, Kessell and Potter (1980) have developed a quantitative succession model for nine of the Montana habitat types of Pfister and others (1977). The model is similar to the one shown in figure 11 in that state transitions are a function of the stand's age and species composition. For each individual habitat type, a table relates quantitative species composition (for all tree species and common undergrowth species) to model states. Unlike the model in figure 11, the Kessell and Potter model allows hot and cool fires to follow different

successional pathways as a function of the calculated (or estimated) fire scorch height. This work does not, however, deal with the variable effect of a given scorch height by species. The reader is referred to Kessell and Potter (1980) for further details.

Numerous other succession research efforts are underway. We anticipate a continued, though perhaps slow, improvement in our understanding of and ability to predict postfire plant successions in coniferous forest communities.

Discussion

The methods and models described here are presented specifically to help integrate fire management considerations into the land management planning process. Many of the models presented here contain simplifying assumptions and should not be used literally in their present form. They can, however, be adapted for use by forest managers who have plant succession information available. These types of models are tools



1/stand age in years

Figure 11.—A more refined version of the figure 10 model includes additional states and more closely approximates observed changes in species composition. (See text for further explanation.)

which can help managers organize, interpret, and understand their own information. In some cases, their use may show a manager where the collection of additional information is desirable.

Despite the relative complexity of some of these tools, a number of difficult and basically unanswered questions about postfire plant succession remain. The first involves the difficult problem of predicting vegetation mortality as a function of fire intensity or some other fire behavior measure. One approach is to conduct research and build models that relate tree mortality to foliage and cambium mortality, which in turn are related to fire intensity, which in turn is related to fuel and weather conditions.

Another problem concerns the extrapolation of data and results from one forest area to another. Will a model developed for the Lewis and Clark National Forest work on the Helena National Forest or in Glacier National Park? Our limited experience suggests that the results of a broad stratification system, such as the habitat type fire groups, may be extrapolated with care over a fairly large area, provided that local field checks and adjustments are made as necessary. Extrapolation of models using

more refined resolution levels, such as individual habitat types, requires more care; a good starting point might be to use them (with field checks) only within a single "forest region" (Arno 1979). Highly refined and detailed local models may be valid only for the area and data base from which they were developed.

Still another problem is the inherent weakness of the models themselves. For example, the models described here assume that lodgepole pine reproduces either from dispersed seeds or from seeds stored in serotinous cones. In the first circumstance, it remains in the community under any fire periodicity, but under the second condition its presence can be greatly diminished in the community under certain fire regimens. As we noted earlier, most natural populations are a mixture of both types; we therefore have modeled a continuous set of responses by assuming only two extreme possibilities. Yet, to adequately include this effect in the model, we would have to build a much more complicated one which requires data that we simply do not have available.

In any modeling effort, we must constantly balance the desire to make a model realistic while keeping it

manageable. This requires the rational selection of compromises. This is especially true in modeling fire effects, where constraints of time, data, and funds are constant concerns to the manager and researcher alike. Yet, we do feel that there are a number of methods and tools presently available to the land manager which can help him better apply his existing understanding and information. We hope that this paper can help accomplish this in the area of predicting postfire plant succession.

PUBLICATIONS CITED

- Aldrich, D. F., and R. W. Mutch
1973. Wilderness fire management: planning guidelines and inventory procedures. USDA For. Serv., North. Reg., Missoula, Mont.
- Arno, S. F.
1976. The historical role of fire in the Bitterroot National Forest. USDA For. Serv. Res. Pap. INT-187, 29 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Arno, S. F.
1979. Forest regions of Montana. USDA For. Serv. Res. Pap. INT-218, 39 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Cattellino, P. J., I. R. Noble, R. O. Slatyer, and S. R. Kessell
1979. Predicting the multiple pathways of plant succession. *Environ. Manage.* 3(1):41-50.
- Clements, F. E.
1916. Plant succession: an analysis of the development of vegetation. Carnegie Inst. Publ. No. 242, 512 p.
- Connell, J. H., and R. O. Slatyer.
1977. Mechanisms of succession in natural communities and their role in community stability and organization. *Am. Nat.* 111:1119-1144.
- Davis, K. M., B. D. Clayton, and W. C. Fischer.
1980. Fire ecology of Lolo National Forest habitat types. USDA For. Serv. Gen. Tech. Rep. INT-79, 77 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Kessell, S. R.
1979a. Gradient modeling: resource and fire management. (Vol. 1, Springer series on Environmental Management.) 433 p. Springer-Verlag, New York.
- Kessell, S. R.
1979b. Phytosociological inference and resource management. *Environ. Manage.* 3(1):29-40.
- Kessell, S. R., and M. W. Potter.
1980. A quantitative succession model of nine Montana forest communities. *Environ. Manage.* 4: [in press].
- Lyon, L. J., and P. F. Stickney.
1976. Early vegetal succession following large northern Rocky Mountain wildfires. *Tall Timbers Fire Ecol. Conf. Proc.* 14:353-375. Tall Timbers Res. Stn., Tallahassee, Fla.
- Lotan, J. E.
1975. The role of cone serotiny in lodgepole pine forests. *In* Management of lodgepole pine ecosystems. p. 471-495. D. M. Baumgartner, ed. Washington State Univ., Pullman.
- Noble, I. R., and R. O. Slatyer.
1977. Postfire succession of plants in Mediterranean ecosystems. *In* Proc. Symp., The Environmental Consequences of Fire and Fuel Management in Mediterranean Climate Ecosystems. p. 27-36. H. A. Mooney and C. E. Conrad, eds. USDA For. Serv. Gen. Tech. Rep. WO-3. Washington, D. C.
- Perry, D. A., and J. E. Lotan.
1979. A model of fire selection for serotiny in lodgepole pine. *Evolution* 33(3):958-968.
- Pfister, R. D., and S. F. Arno
1980. Classifying forest habitat types based on potential climax vegetation. *For. Sci.* 26(1):52-70
- Pfister, R. D., B. L. Kovalchik, S. F. Arno, and R. C. Presby.
1977. Forest habitat types of Montana. USDA For. Serv. Gen. Tech. Rep. INT-34, 174 p. Intermt. For. and Range Exp. Stn., Ogden, Utah

APPENDIX

HABITAT TYPE FIRE GROUPS FOR MONTANA FORESTS

Fire Group 0 - Miscellaneous special habitats.

Scree;
Forested rock,
Meadow;
Grassy bald,
Alder glade;
Aspen grove.

Fire Group 1 - Dry limber pine habitat types.

Pinus flexilis/*Agropyron spicatum* h.t. (PIFL/AGSP; limber pine/ bluebunch wheatgrass),
Pinus flexilis/*Festuca idahoensis* h.t., *Festuca idahoensis* phase (PIFL/FEID-FEID; limber pine/Idaho fescue, rough fescue phase);
Pinus flexilis/*Festuca idahoensis* h.t., *Festuca scabrella* phase (PIFL/FEID-FESC, limber pine/Idaho fescue, rough fescue phase);
Pinus flexilis/*Juniperus communis* h.t. (PIFL/JUCO; limber pine/common juniper).

Fire Group 2 - Warm, dry ponderosa pine habitat types:

Pinus ponderosa/*Andropogon* spp. h.t. (PIPO/AND; ponderosa pine/bluestem);
Pinus ponderosa/*Agropyron spicatum* h.t. (PIPO/AGSP; ponderosa pine/ bluebunch wheatgrass);
Pinus ponderosa/*Festuca idahoensis* h.t., *Festuca idahoensis* phase (PIPO/FEID-FEID; ponderosa pine/Idaho fescue, Idaho fescue phase);
Pinus ponderosa/*Festuca idahoensis* h.t., *Festuca scabrella* phase (PIPO/FEID-FESC, ponderosa pine/Idaho fescue, rough fescue phase);
Pinus ponderosa/*Purshia tridentata* h.t., *Agropyron spicatum* phase (PIPO/PUTR-AGSP; ponderosa pine/bitterbrush, bluebunch wheatgrass phase);
Pinus ponderosa/*Purshia tridentata* h.t., *Festuca idahoensis* phase (PIPO/PUTR-FEID; ponderosa pine/bitterbrush, Idaho fescue phase);
Pinus ponderosa/*Symphoricarpos albus* h.t., *Symphoricarpos albus* phase (PIPO/SYAL-SYAL; ponderosa pine/snowberry, snowberry phase).

Fire Group 3 - Warm, moist ponderosa pine habitat types:

Pinus ponderosa/*Symphoricarpos albus* h.t., *Berberis repens* phase (PIPO/SYAL-BERE; ponderosa pine/snowberry, creeping Oregon grape phase);
Pinus ponderosa/*Prunus virginiana* h.t., *Prunus vir-*

giniana phase (PIPO/PRVI-PRVI; ponderosa pine/chokecherry, chokecherry phase),
Pinus ponderosa/*Prunus virginiana* h.t., *Shepherdia canadensis* phase (PIPO/PRVI-SHCA; ponderosa pine/chokecherry, buffaloberry phase)

Fire Group 4 - Warm, dry Douglas-fir habitat types

Pseudotsuga menziesii/*Agropyron spicatum* h.t. (PSME/AGSP; Douglas-fir/bluebunch wheatgrass);
Pseudotsuga menziesii/*Festuca scabrella* h.t. (PSME/FESC; Douglas-fir/rough fescue);
Pseudotsuga menziesii/*Physocarpus malvaceus* h.t., *Calamagrostis rubescens* phase (PSME/PHMA-CARU; Douglas-fir/ninebark, pinegrass phase);
Pseudotsuga menziesii/*Symphoricarpos albus* h.t., *Agropyron spicatum* phase (PSME/SYAL-AGSP, Douglas-fir/snowberry, bluebunch wheatgrass phase);
Pseudotsuga menziesii/*Calamagrostis rubescens* h.t., *Pinus ponderosa* phase (PSME/CARU-PIPO; Douglas-fir/pinegrass-ponderosa pine phase);
Pseudotsuga menziesii/*Spiraea betulifolia* h.t. (PSME/SPBE; Douglas-fir/white spiraea phase);
Pseudotsuga menziesii/*Arctostaphylos uva-ursi* h.t. (PSME/ARUV; Douglas-fir/kinnikinnick);
Pseudotsuga menziesii/*Calamagrostis rubescens* h.t., *Agropyron spicatum* phase (PSME/CARU-AGSP; Douglas-fir/pinegrass, bluebunch wheatgrass).

Fire Group 5 - Cool, dry Douglas-fir habitat types:

Pseudotsuga menziesii/*Calamagrostis rubescens* h.t., *Agropyron spicatum* phase (PSME/CARU-AGSP; Douglas-fir/pinegrass, bluebunch wheatgrass phase);
Pseudotsuga menziesii/*Festuca idahoensis* h.t. (PSME/FEID; Douglas-fir/Idaho fescue);
Pseudotsuga menziesii/*Carex geyeri* h.t. (PSME/CAGE; Douglas-fir/elk sedge);
Pseudotsuga menziesii/*Arnica cordifolia* h.t. (PSME/ARCO; Douglas-fir/heartleaf arnica);
Pseudotsuga menziesii/*Symphoricarpos oreophilus* h.t. (PSME/SYOR; Douglas-fir/mountain snowberry);
Picea/Senecio streptanthifolius h.t., *Pseudotsuga menziesii* phase (PICEA/SEST-PSME; spruce/cleft-leaf groundsel, Douglas-fir phase).

Fire Group 6 - Moist Douglas-fir habitat types:

Pseudotsuga menziesii/*Physocarpus malvaceus* h.t., *Physocarpus malvaceus* phase (PSME/PHMA-PHMA; Douglas-fir/ninebark, ninebark phase);

Pseudotsuga menziesii/Vaccinium globulare h.t., *Vaccinium globulare* phase (PSME/VAGL-VAGL; Douglas-fir/blue huckleberry, blue huckleberry phase);

Pseudotsuga menziesii/Vaccinium globulare h.t., *Arctostaphylos uva-ursi* phase (PSME/VAGL-ARUV; Douglas-fir/blue huckleberry, kinnikinnick);

Pseudotsuga menziesii/Vaccinium globulare h.t., *Xerophyllum tenax* phase (PSME/VAGL-XETE; Douglas-fir/blue huckleberry, beargrass phase);

Pseudotsuga menziesii/Linnaea borealis h.t., *Symphoricarpos albus* phase (PSME/LIBO-SYAL; Douglas-fir/twinflower, snowberry phase);

Pseudotsuga menziesii/Linnaea borealis h.t., *Calamagrostis rubescens* phase (PSME/LIBO-CARU; Douglas-fir/twinflower, pinegrass phase);

Pseudotsuga menziesii/Linnaea borealis h.t., *Vaccinium globulare* phase (PSME/LIBO-VAGL; Douglas-fir/twinflower, blue huckleberry phase);

Pseudotsuga menziesii/Symphoricarpos albus h.t., *Calamagrostis rubescens* phase (PSME/SYAL-CARU; Douglas-fir/snowberry, pinegrass phase);

Pseudotsuga menziesii/Symphoricarpos albus h.t., *Symphoricarpos albus* phase (PSME/SYAL-SYAL; Douglas-fir/snowberry, snowberry phase);

Pseudotsuga menziesii/Calamagrostis rubescens h.t., *Arctostaphylos uva-ursi* phase (PSMA/CARU-ARUV; Douglas-fir/pinegrass, kinnikinnick phase);

Pseudotsuga menziesii/Calamagrostis rubescens h.t., *Calamagrostis rubescens* phase (PSME/CARU-CARU; Douglas-fir/pinegrass, pinegrass phase);

Pseudotsuga menziesii/Vaccinium caespitosum h.t. (PSME/VACA; Douglas-fir/dwarf huckleberry);

Pseudotsuga menziesii/Juniperus communis h.t. (PSME/JUCO; Douglas-fir/common juniper).

Fire Group 7 - Cool habitat types usually dominated by lodgepole pine:

Pseudotsuga menziesii/Juniperus communis h.t. (PSME/JUCO; Douglas-fir/common juniper);

Pseudotsuga menziesii/Vaccinium caespitosum h.t. (PSME/VACA; Douglas-fir/dwarf huckleberry);

Picea/Vaccinium caespitosum h.t. (PICEA/VACA; spruce/dwarf huckleberry);

Picea/Linnaea borealis h.t. (PICEA/LIBO; spruce/twinflower);

Abies lasiocarpa/Vaccinium caespitosum h.t. (ABLA/VACA; subalpine fir/dwarf huckleberry);

Abies lasiocarpa/Calamagrostis canadensis h.t., *Vaccinium caespitosum* phase (ABLA/CACA-VACA; subalpine fir/dwarf huckleberry);

Abies lasiocarpa/Calamagrostis canadensis h.t., *Vaccinium caespitosum* phase (ABLA/CACA-VACA; subalpine fir/bluejoint, dwarf huckleberry phase);

Abies lasiocarpa/Linnaea borealis h.t., *Vaccinium scoparium* phase (ABLA/LIBO-VASC; subalpine fir/twinflower, grouse whortleberry phase);

Abies lasiocarpa/Xerophyllum tenax h.t., *Vaccinium scoparium* phase (ABLA/XETE-VASC; subalpine fir/beargrass, grouse whortleberry phase);

Abies lasiocarpa/Vaccinium globulare h.t. (ABLA/VAGL; subalpine fir/blue huckleberry);

Abies lasiocarpa/Vaccinium scoparium h.t., *Calamagrostis rubescens* phase (ABLA/VASC-CARU; subalpine fir/grouse whortleberry, pinegrass phase);

Abies lasiocarpa/Vaccinium scoparium h.t., *Vaccinium scoparium* phase (ABLA/VASC-VASC; subalpine fir/grouse whortleberry, grouse whortleberry phase);

Abies lasiocarpa/Carex geyeri h.t., *Carex geyeri* phase (ABLA/CAGE-CAGE; subalpine fir/elk sedge, elk sedge phase);

Pinus contorta/Purshia tridentata h.t. (PICO/PUTF; lodgepole pine/bitterbrush);

Pinus contorta/Vaccinium caespitosum h.t. (PICO/VACA; lodgepole pine/dwarf huckleberry);

Pinus contorta/Linnaea borealis h.t. (PICO/LIBO; lodgepole pine/twinflower);

Pinus contorta/Vaccinium scoparium h.t. (PICO/VASC; lodgepole pine/grouse whortleberry);

Pinus contorta/Calamagrostis rubescens h.t. (PICO/CARU; lodgepole pine/pinegrass).

Fire Group 8 - Dry, lower subalpine habitat types.

Picea/Physocarpus malvaceus h.t. (PICEA/PHMA; spruce/ninebark);

Picea/Senecio streptanthifolius h.t. (PICEA/SEST; spruce/cleft-leaf groundsel);

Abies lasiocarpa/Xerophyllum tenax h.t., *Vaccinium globulare* phase (ABLA/XETE-VAGL; subalpine fir/beargrass, blue huckleberry phase);

Tsuga mertensiana/Xerophyllum tenax h.t. (TSME/XETE; mountain hemlock/beargrass);

Abies lasiocarpa/Vaccinium scoparium h.t., *Thalictrum occidentale* phase (ABLA/VASC-THOC; subalpine fir/grouse whortleberry, western meadowrue phase);

Abies lasiocarpa/Calamagrostis rubescens h.t. (ABLA/CARU; subalpine fir/pinegrass);

Abies lasiocarpa/Clematis pseudoalpina h.t. (ABLA/CLPS; subalpine fir/virgin's bower);

Abies lasiocarpa/Arnica cordifolia h.t. (ABLA/AROC; subalpine fir/heartleaf arnica);

Abies lasiocarpa/Carex geyeri h.t., *Pseudotsuga menziesii* phase (ABLA/CAGE-PSME; subalpine fir/elk sedge, Douglas-fir phase).

Fire Group 9 - Moist, lower subalpine habitat types:

Picea/Equisetum arvense h.t. (PICEA/EQAR; spruce/common horsetail;
Picea/Clintonia uniflora h.t., *Vaccinium caespitosum* phase (PICEA/CLUN-VACA; spruce/queencup beadlily, dwarf huckleberry phase);
Picea/Clintonia uniflora h.t., *Clintonia uniflora* phase (PICEA/CLUN-CLUN; spruce/queencup beadlily, queencup beadlily phase);
Picea/Galium triflorum h.t. (PICEA/GATR; spruce/sweetscented bedstraw);
Abies lasiocarpa/Oplodanox horridus h.t. (ABLA/OPHO; subalpine fir/devil's club);
Abies lasiocarpa/Clintonia uniflora h.t., *Clintonia uniflora* phase (ABLA/CLUN-CLUN; subalpine fir/queencup beadlily, wild sarsaparilla phase);
Abies lasiocarpa/Clintonia uniflora h.t., *Aralia nudicaulis* phase (ABLA/CLUN-ARNU; subalpine fir/queencup beadlily, wild sarsaparilla phase);
Abies lasiocarpa/Clintonia uniflora h.t., *Vaccinium caespitosum* phase (ABLA/CLUN-VACA; subalpine fir/queencup beadlily, dwarf huckleberry phase);
Abies lasiocarpa/Clintonia uniflora h.t., *Xerophyllum tenax* phase (ABLA/CLUN-XETE; subalpine fir/queencup beadlily, beargrass phase);
Abies lasiocarpa/Clintonia uniflora h.t., *Menziesia ferruginea* phase (ABLA/CLUN-MEFE; subalpine fir/queencup beadlily, menziesia phase);
Abies lasiocarpa/Galium triflorum h.t. (ABLA/GATR; subalpine fir/sweetscented bedstraw);
Abies lasiocarpa/Calamagrostis canadensis h.t., *Calamagrostis canadensis* phase (ABLA/CACA-CACA; subalpine fir/bluejoint, bluejoint phase);
Abies lasiocarpa/Calamagrostis canadensis h.t., *Galium triflorum* phase (ABLA/CACA-GATR; subalpine fir/bluejoint, sweetscented bedstraw phase);
Abies lasiocarpa/Linnaea borealis h.t., *Linnaea borealis* phase (ABLA/LIBO-LIBO; subalpine fir/twinflower, twinflower phase);
Abies lasiocarpa/Linnaea borealis h.t., *Linnaea borealis* phase (ABLA/LIBO-LIBO; subalpine fir/twinflower, twinflower phase);
Abies lasiocarpa/Linnaea borealis h.t., *Xerophyllum tenax* phase (ABLA/LIBO-XETE; subalpine fir/twinflower, beargrass phase);
Abies lasiocarpa/Linnaea borealis h.t., *Menziesia ferruginea* h.t. (ABLA/LIBO-MEFE; subalpine fir/twinflower, menziesia phase);
Abies lasiocarpa/Linnaea borealis h.t., *Menziesia ferruginea* h.t. (TSME/LIBO-MEFE; subalpine fir/twinflower, menziesia phase);
Abies lasiocarpa/Linnaea borealis h.t., *Linnaea borealis* phase (ABLA/LIBO-LIBO; subalpine fir/twinflower, twinflower phase);
Abies lasiocarpa/Linnaea borealis h.t., *Xerophyllum tenax* phase (ABLA/LIBO-XETE; subalpine fir/twinflower, beargrass phase);

Fire Group 10 - Cold, moist upper subalpine and timberline habitat types:

Picea/Senecio streptanthifolius h.t., *Picea* phase (PICEA/SEST-PICEA; spruce/cleft-leaf groundsel, spruce phase);
Abies lasiocarpa/Ribes montigenum h.t. (ABLA/RIMO; subalpine fir/mountain gooseberry);
Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium h.t. (ABLA-PIAL/VASC; subalpine fir-whitebark pine/grouse whortleberry);
Abies lasiocarpa/Luzula hitchcockii h.t., *Vaccinium scoparium* phase (ABLA/LUHI-VASC; subalpine fir/smooth woodrush, grouse whortleberry phase);
Abies lasiocarpa/Luzula hitchcockii h.t., *Menziesia ferruginea* phase (ABLA/LUHI-MEFE; subalpine fir/smooth woodrush, menziesia phase);
Tsuga mertensiana/Luzula hitchcockii h.t., *Vaccinium scoparium* phase (TSME/LUHI-VASC; mountain hemlock/smooth woodrush, grouse whortleberry phase);
Tsuga mertensiana/Luzula hitchcockii h.t., *Menziesia ferruginea* phase (TSME/LUHI-MEFE; mountain hemlock/smooth woodrush, menziesia phase);
Pinus albicaulis-Abies lasiocarpa h.t.'s (PIAL-ABLA h.t.'s; whitebark pine-subalpine fir);
Larix laricina-Abies lasiocarpa h.t.'s (LALY-PIAL h.t.'s; alpine larch-subalpine fir);
Pinus albicaulis h.t.'s (PIAL h.t.'s; whitebark pine)

Fire Group 11 - Warm, moist grand fir, western hemlock, and western redcedar habitat types:

Abies grandis/Xerophyllum tenax h.t. (ABGR/XETE; grand fir/beargrass);
Abies grandis/Clintonia uniflora h.t., *Clintonia uniflora* phase (ABGR/CLUN-CLUN; grand fir/queencup beadlily, queencup beadlily phase);
Abies grandis/Clintonia uniflora h.t., *Clintonia uniflora* phase (ABGR/CLUN-CLUN; grand fir/queencup beadlily, queencup beadlily phase);
Abies grandis/Clintonia uniflora h.t., *Aralia nudicaulis* phase (ABGR/CLUN-ARNU; grand fir/queencup beadlily, wild sarsaparilla phase);
Abies grandis/Clintonia uniflora h.t., *Xerophyllum tenax* phase (ABGR/CLUN-XETE; grand fir/queencup beadlily, beargrass phase);
Abies grandis/Linnaea borealis h.t., *Linnaea borealis* phase (ABGR/LIBO-LIBO; grand fir/twinflower, twinflower phase);
Abies grandis/Linnaea borealis h.t., *Xerophyllum tenax* phase (ABGR/LIBO-XETE; grand fir/twinflower, beargrass phase);

Thuja plicata/*Clintonia uniflora* h t , *Clintonia uniflora* phase (THPL/CLUN-CLUN; Western redcedar/queencup beadlily, queencup beadlily phase);

Thuja plicata/*Clintonia uniflora* h.t., *Aralia nudicaulis* phase (THPL/CLUN-ARNU, western redcedar/queencup beadlily, wild sarsaparilla phase);

Thuja plicata/*Clintonia uniflora* h t , *Menziesia ferruginea* phase (THPL/CLUN-MEFE; western redcedar/queencup beadlily, menziesia phase);

Thuja plicata/*Oplopanax horridus* h.t. (THPL/OPHO, western redcedar/devil's club);

Tsuga heterophylla/*Clintonia uniflora* h t , *Clintonia uniflora* phase (TSHE/CLUN-CLUN, western hemlock/queencup beadlily, queencup beadlily phase),

Tsuga heterophylla/*Clintonia uniflora* h.t., *Aralia nudicaulis* phase (TSHE/CLUN-ARNU; western hemlock/queencup beadlily, wild sarsaparilla phase).

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KEYWORDS forest succession, fire effects, fire management

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